Conclusions of the Bolund Experiment and Blind Comparison

Bechmann, Andreas; Sørensen, Niels N.; Berg, Jacob; Mann, Jakob; Réthoré, Pierre-Elouan Mikael

Published in:
Proceedings

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

Conclusions of the Bolund Experiment and Blind Comparison

A. Bechmann, P-E Rethore, N.N. Sørensen, J. Berg, H.E. Jørgensen, J. Mann, M. Courtney, P. Hansen

In corporation with Vestas

EERA Workshop on Wind conditions - University of Porto, 26-28 January 2011

Risø DTU
National Laboratory for Sustainable Energy

Vestas

Content

1. The Experiment
2. The Blind Comparison
3. Conclusions
4. Bolund's Big Brother?

Wind Turbines in Complex Terrain

Do the models work here?





Askervein and Bolund

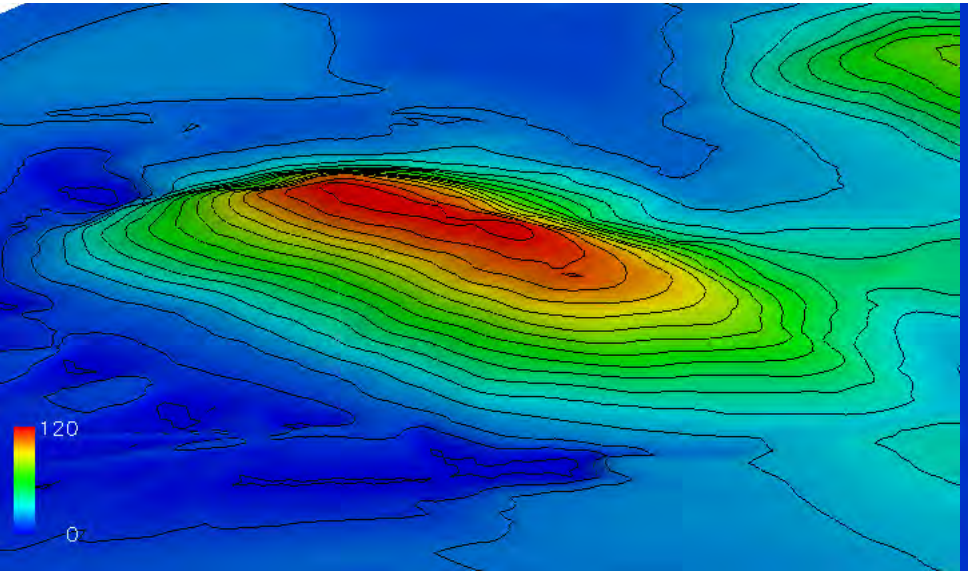
Cases for validation of flow models

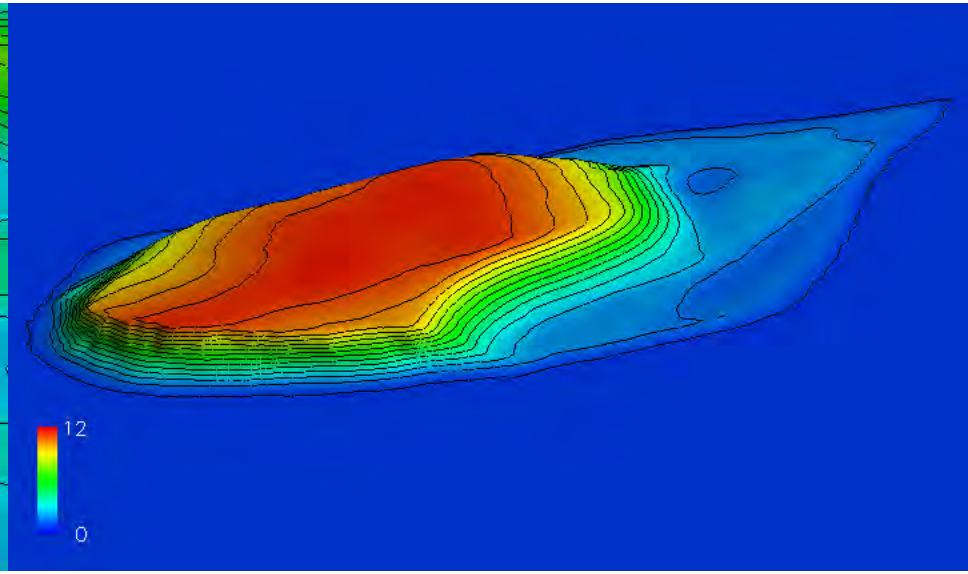
Askervein Experiment 1983

- Low hill with gentle slope (<20^{o})
- Well-defined inflow and
- Uniform roughness

Bolund Experiment 2008

- Steep escarpment
- Well-defined inflow conditions
- Roughness change





Askervein and Bolund

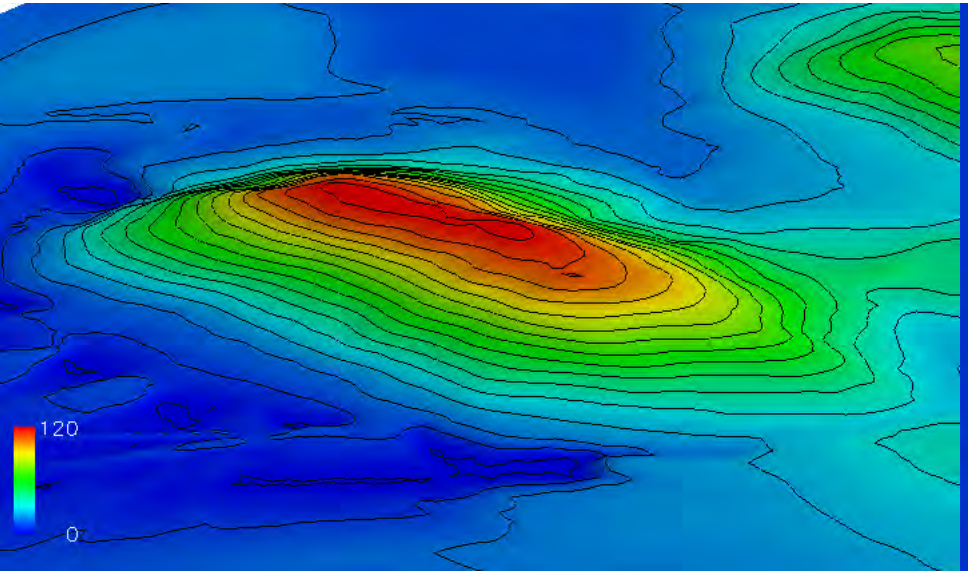
Scale Effects

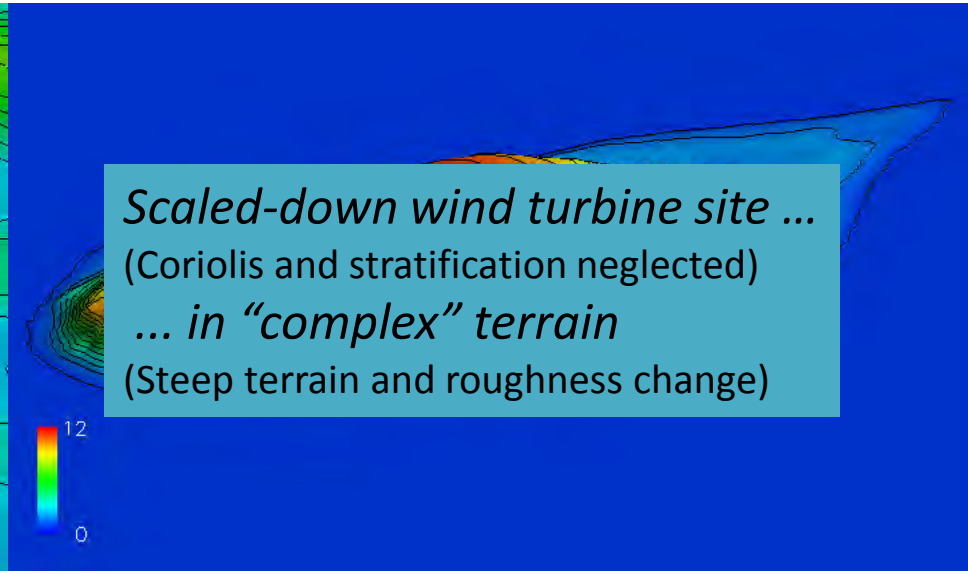
Askervein Experiment 1983

- Stability (h=116 m): $h \sim L_{MO}$
- Reynolds (U=10 ms^{-1}): 10^8
- Rossby (L=1000 m): 100

Bolund Experiment 2008

- Stability (h=12 m): $h << L_{MO}$
- Reynolds (U=10 ms^{-1}): 10^7
- Rossby (L=150 m): 700

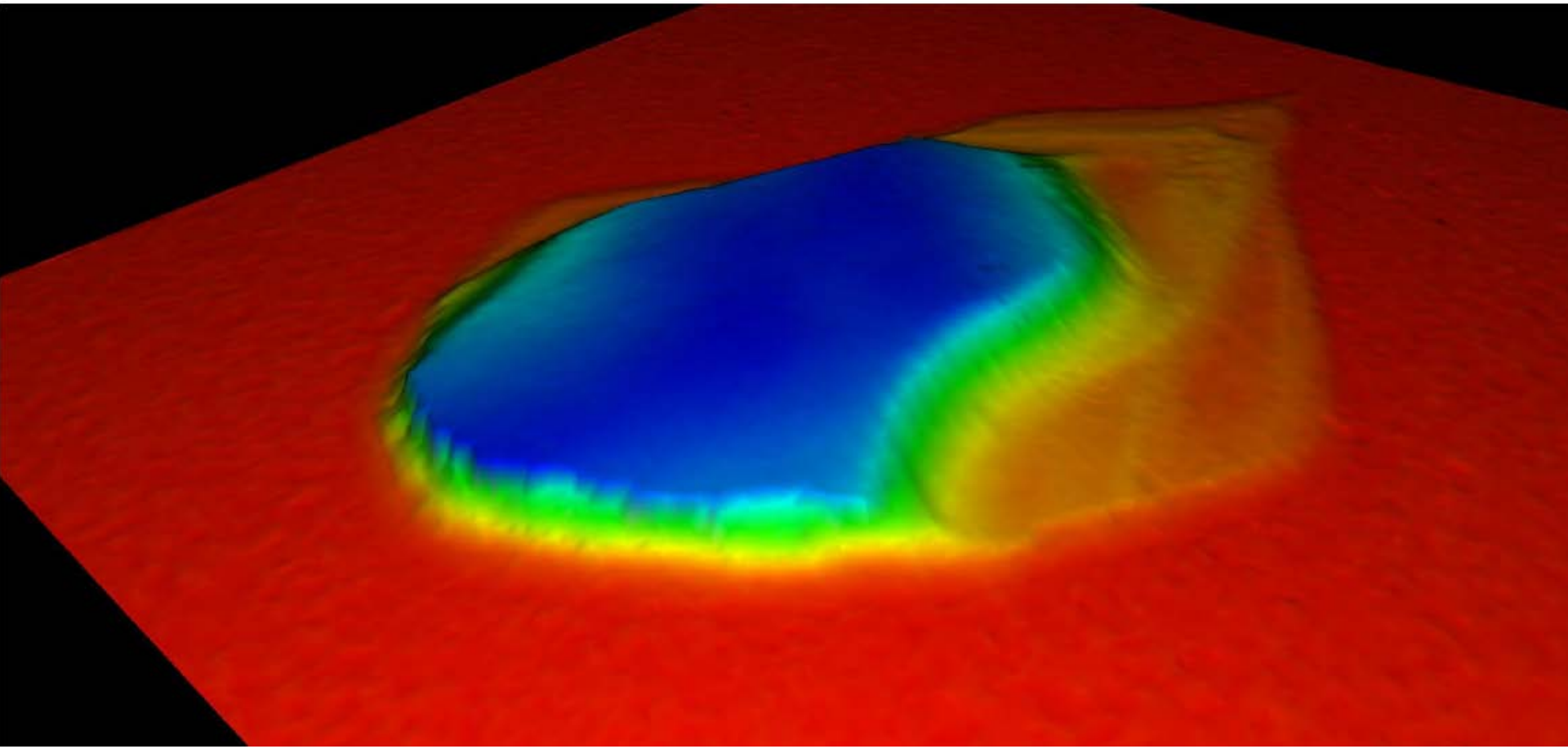




Scaled-down wind turbine site …
(Coriolis and stratification neglected)
… in "complex" terrain
(Steep terrain and roughness change)

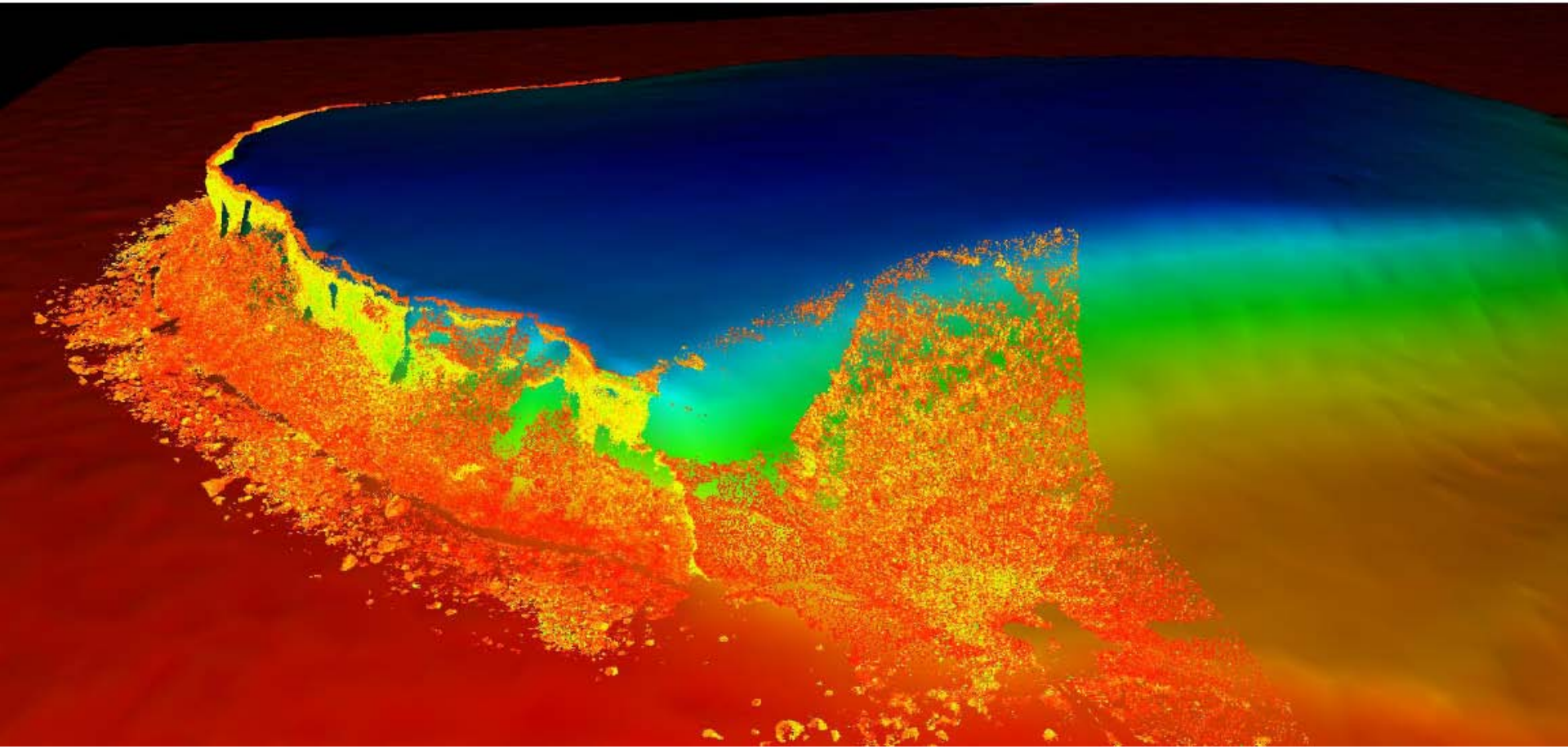
Height Scanning with laser

Optech Airborne Laser Terrain Mapper: ≈ 2 m resolution



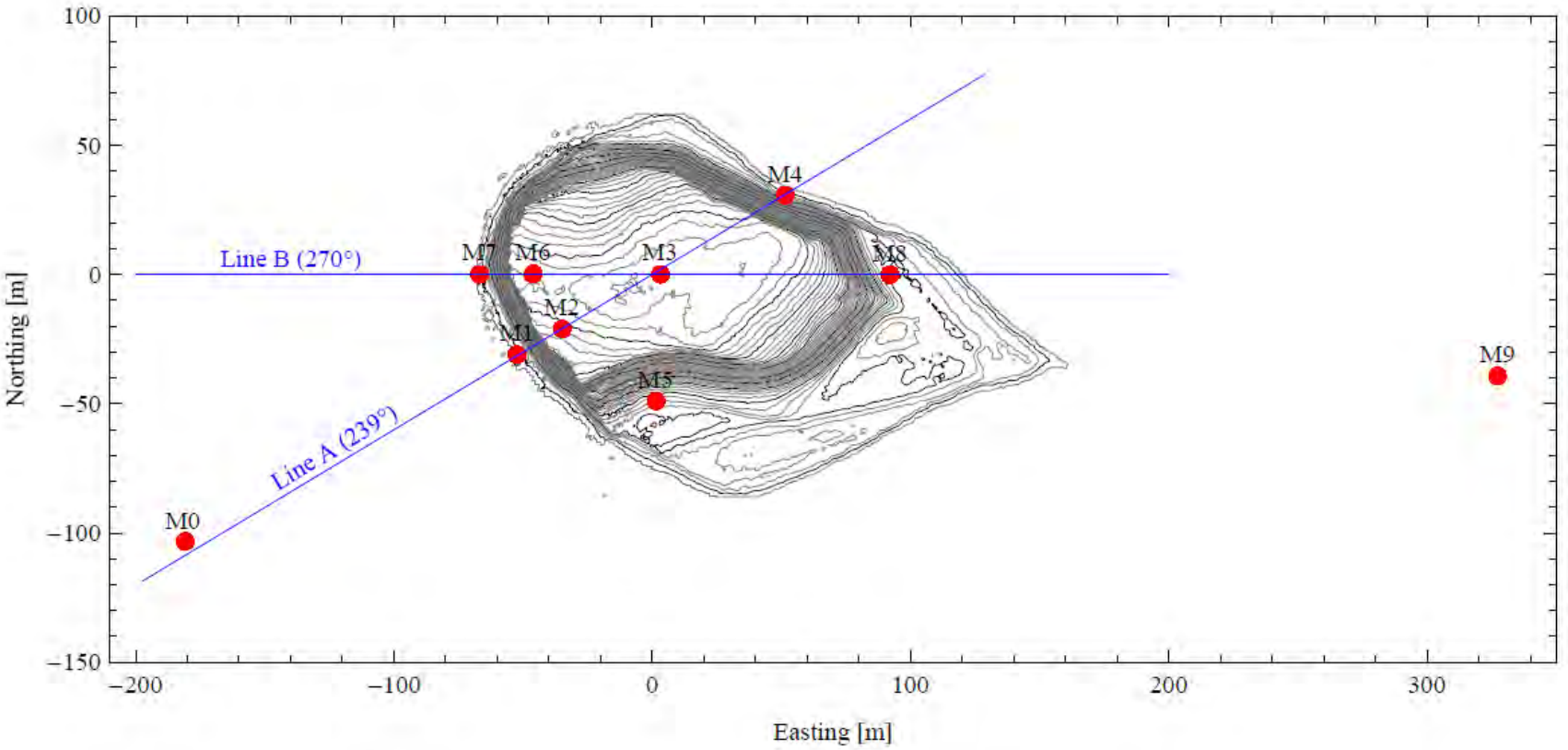
Height Scanning with laser

Cliff to steep: additional < 0.1 m resolution scanning applied



Mast Positions

CFD were used to find the 10 positions



Erecting the Masts

Since Bolund is protected no machinery could be used

Instrumentation

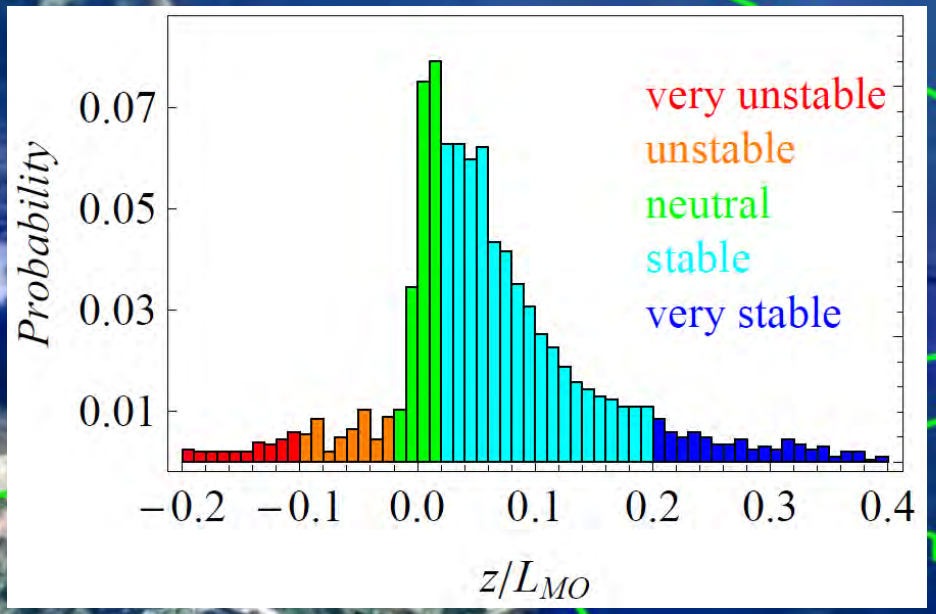
23 Metek Sonics, 2 ZephIR Lidars, 12 Risø Cups

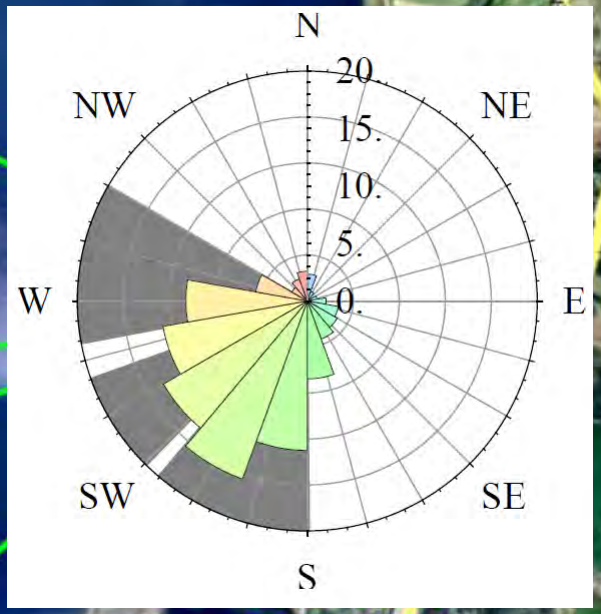



Direct Data Transfer to Risø via RadioLink (20 Hz) and Online Data display

Upstream Conditions

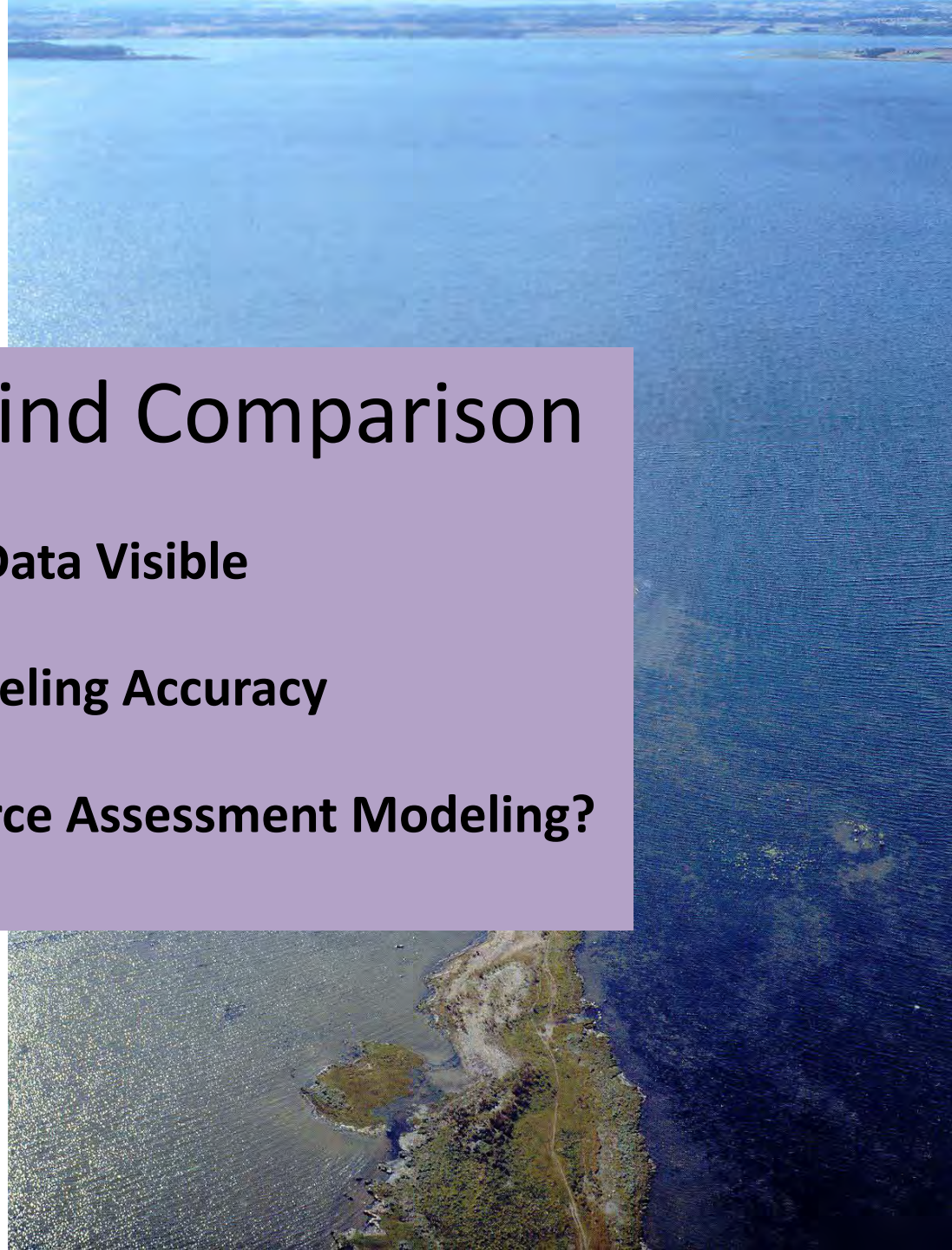
Sonic data coverage of 92%





Content

1. The Experiment
2. The Blind Comparison
3. Conclusions
4. Bolund's Big Brother?



Purpose of Blind Comparison

1. **Make The Bolund Data Visible**
2. **Evaluate Flow Modeling Accuracy**
3. **Standardize Resource Assessment Modeling?**

Workshop

80 participants joined the workshop

Blind Comparison

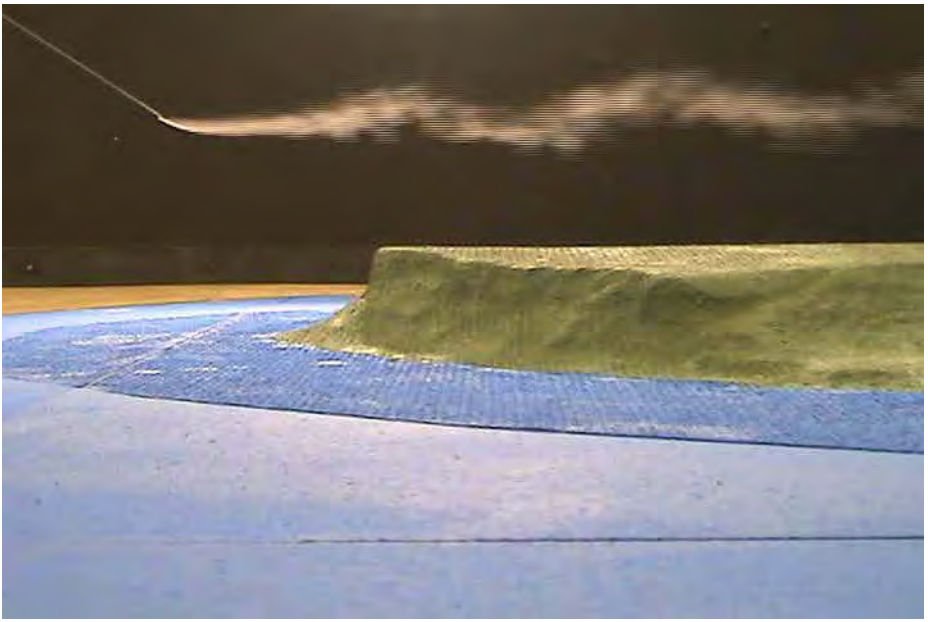
40 companies/universities, 57 model results

Model types:

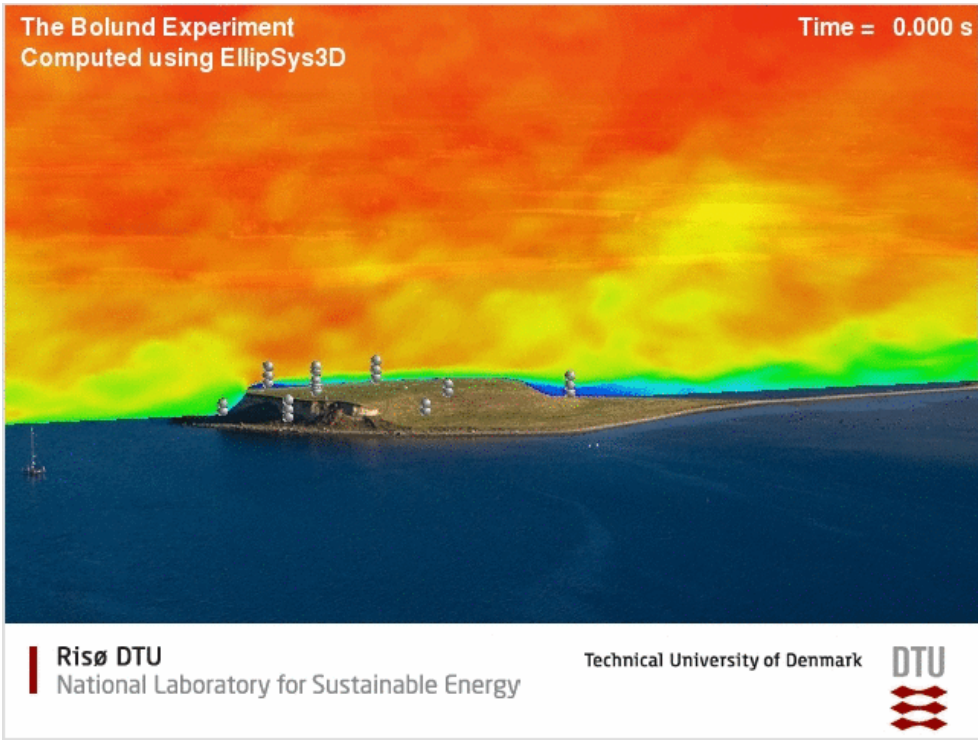
- 2: Experimental method
  - 1: Wind tunnel
  - 1: Flow channel
- 11: Linearized flow model
  - 3: WAsP like
  - 5: WAsP Eng.
- 4: No answer
- 40: Non-linear CFD model
  - 6: LES / hybrid RANS-LES
  - 6: RANS 1 eqn.
  - 27: RANS 2 eqn. 24 k-ε models!

Model visualization

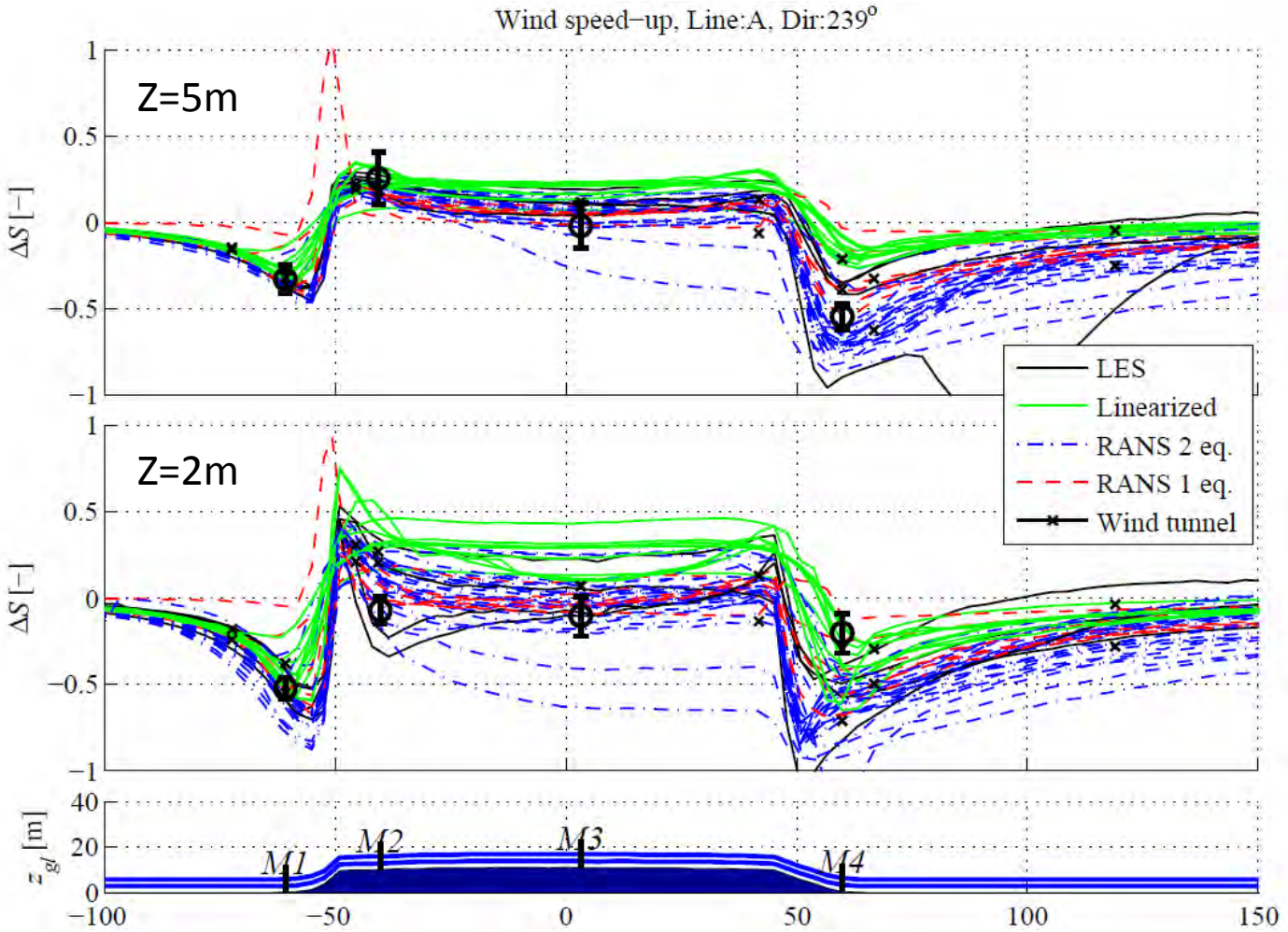
Wind Tunnel and LES



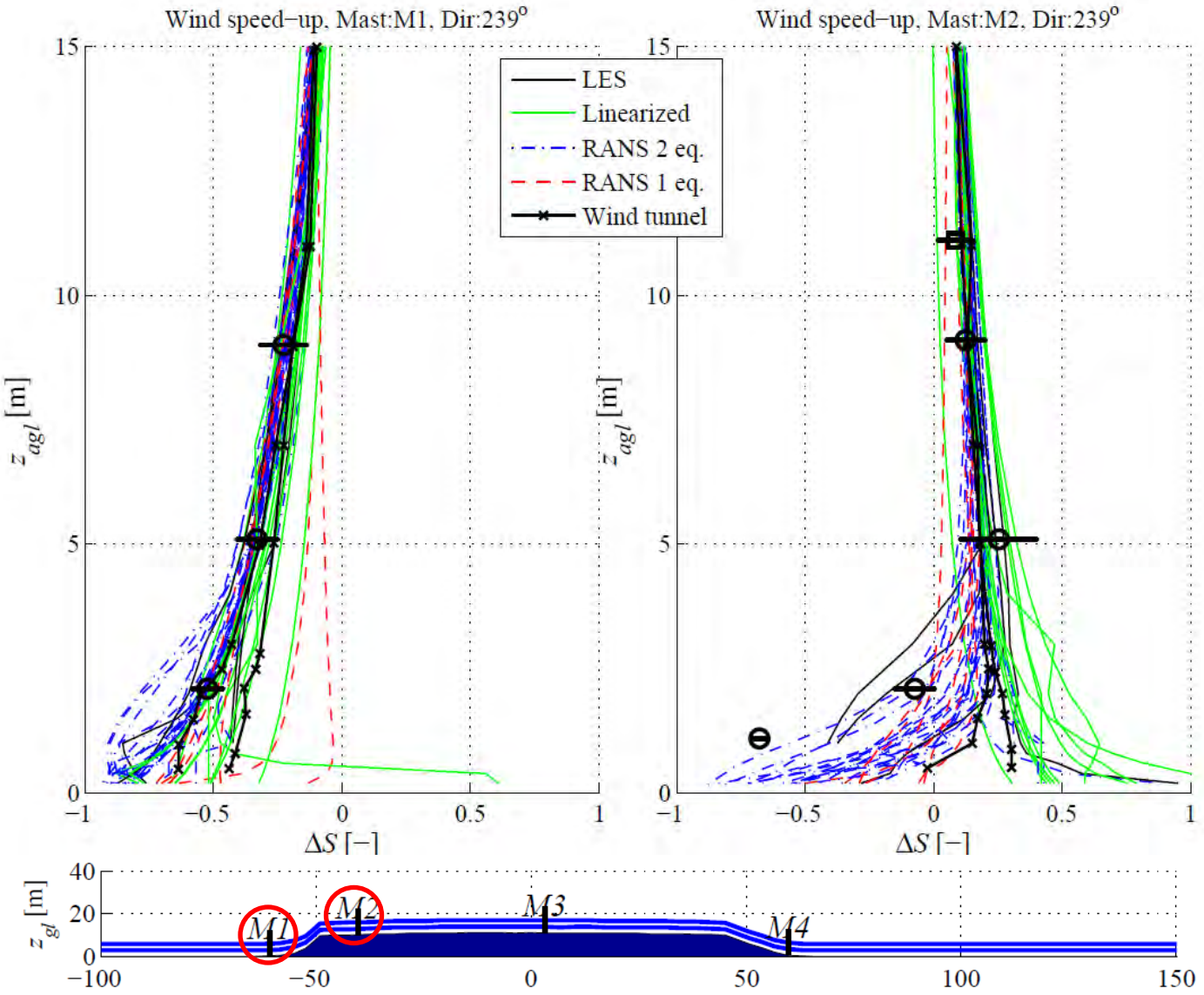
By: Brad C. Cochran (cppwind.com)



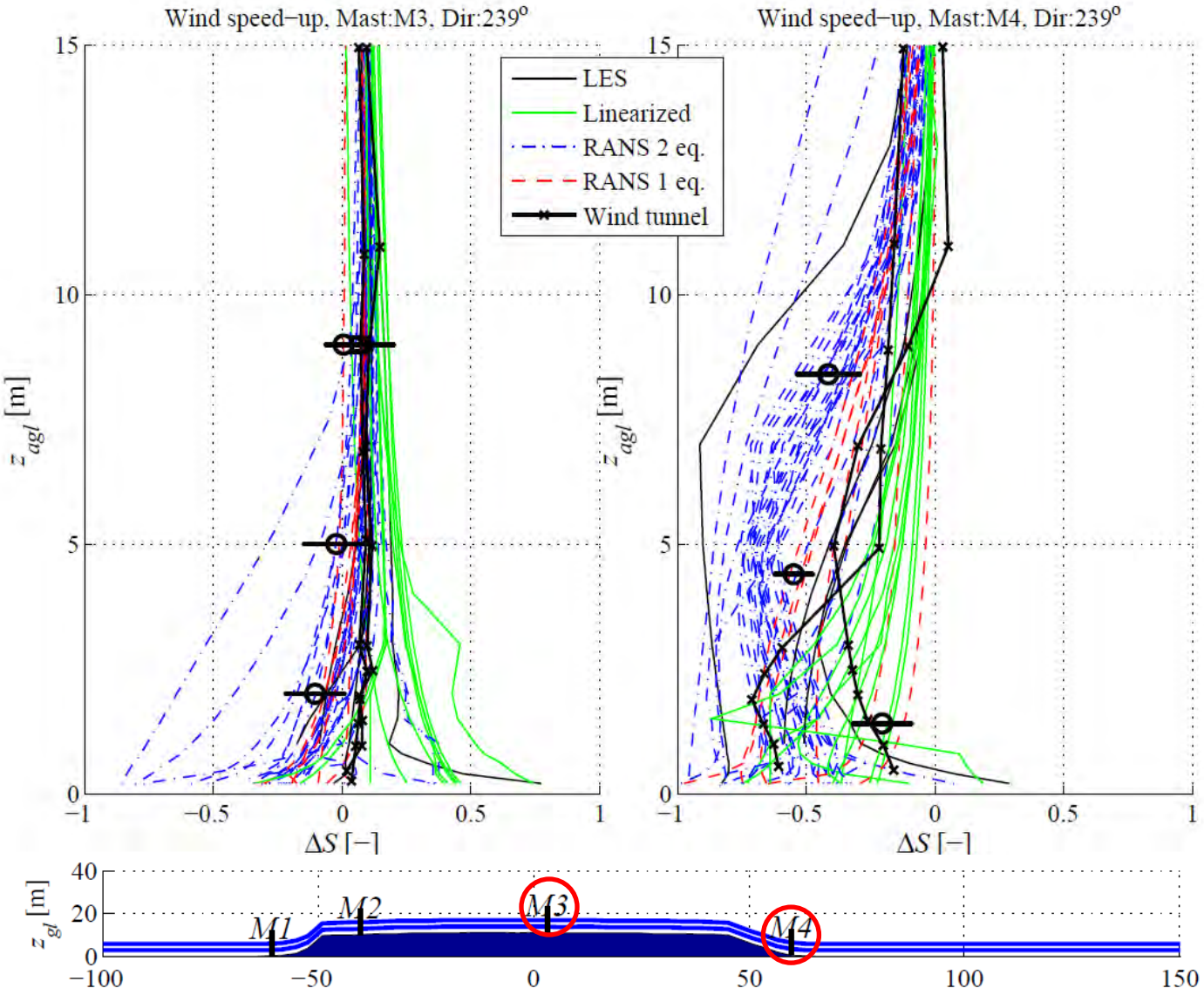
Speed-up along line A



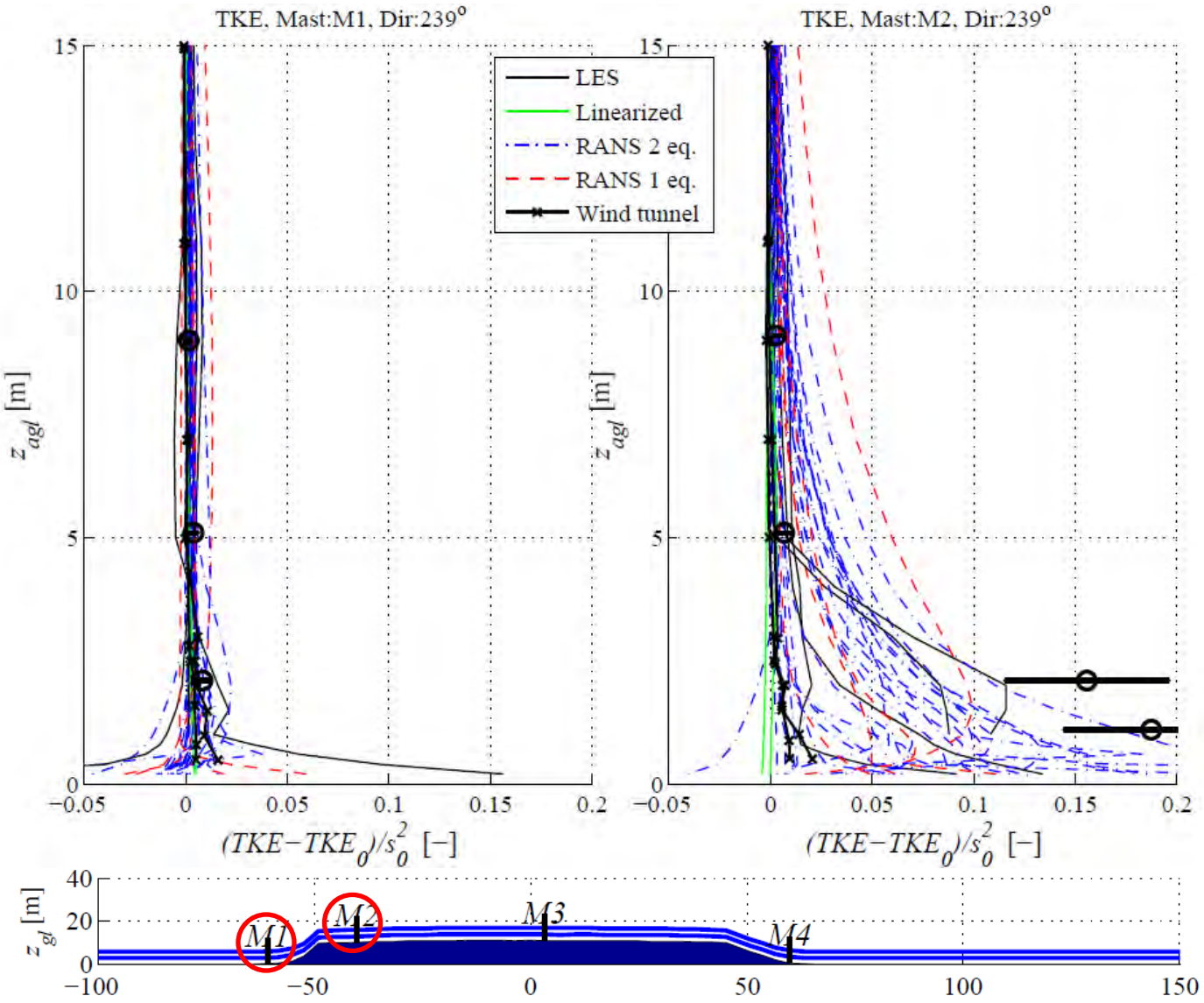
Speed-up at M1 & M2



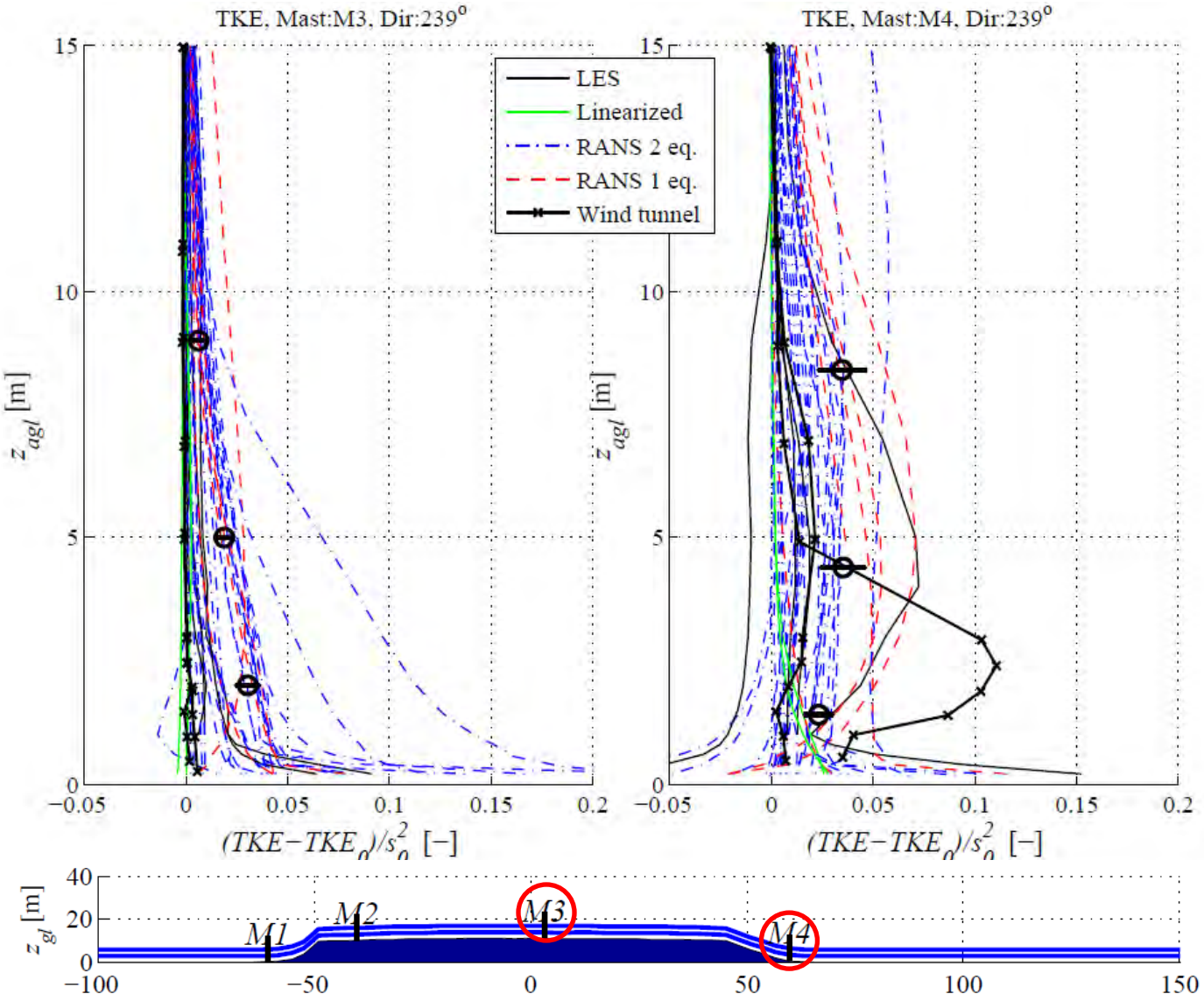
Speed-up at M3 & M4



TKE-up at M1 & M2



TKE-up at M3 & M4



Quantifying the model errors

Speed-up error

- Linear assumptions violated
- LES shows the largest errors
- For z > 5m the error is 6.5%

$$R_S = 100\,(\Delta S_s - \Delta S_m)$$

	Case 1+3
RANS 2 eq.	15.1 (11.4)
Experiment	14.7 (13.3)
RANS 1 eq.	17.2 (13.8)
LES	17.3 (14.1)
Linearised	23.7 (20.6)
All models	17.3

TKE error

- LES does better than experiment
- Steady RANS performs the best

$$R_{TKE} = 100\left(\frac{(I_s - I_{0s}) - (I_m - I_{0m})}{I_{0m}}\right)$$

	Case 1+3
RANS 2 eq.	47.0 (29.9)
LES	48.0 (41.6)
RANS 1 eq.	44.7 (42.7)
Experiment	61.4 (59.4)
Linearised	76.7 (71.4)
All models	49.5

Content

1. The Experiment
2. The Blind Comparison
3. Conclusions
4. Bolund's Big Brother?

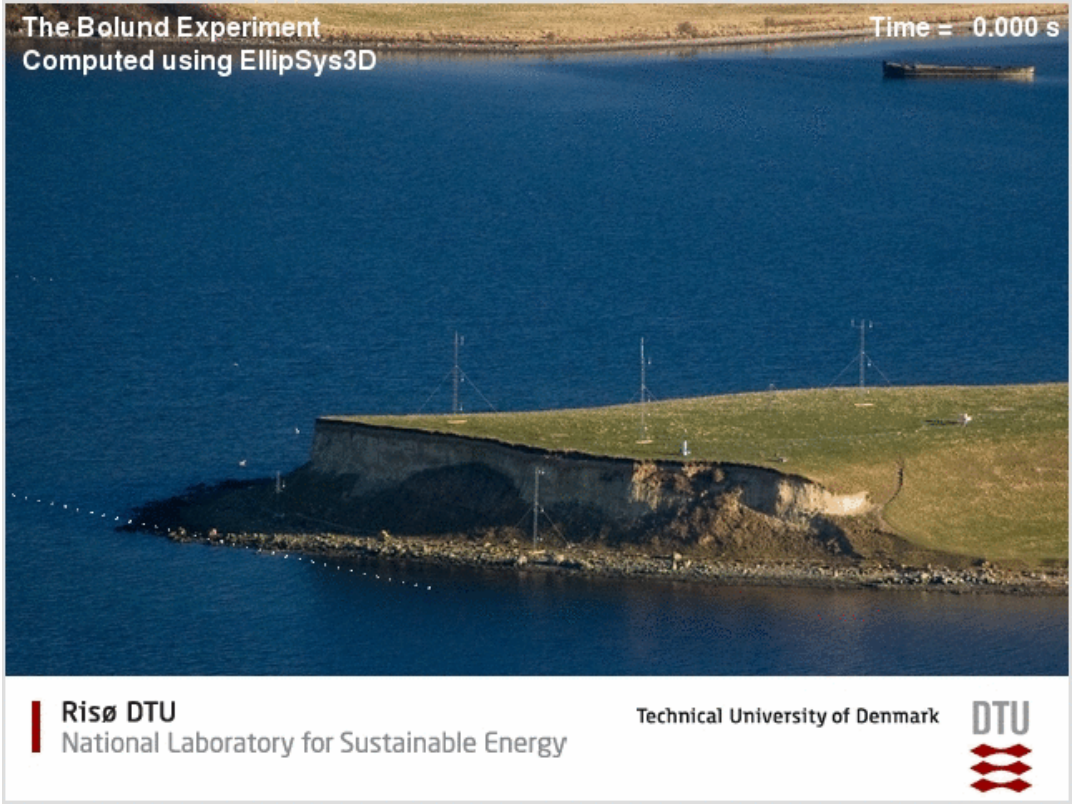
Conclusions

The Experiment

1. Instrumentation and data acquisition worked well. Proximity to Risø – convenient.

2. We have successfully captured the gross features of flow over a steep hill.

3. Should we do it over again: only measure along one line, but more heavily instrumented.



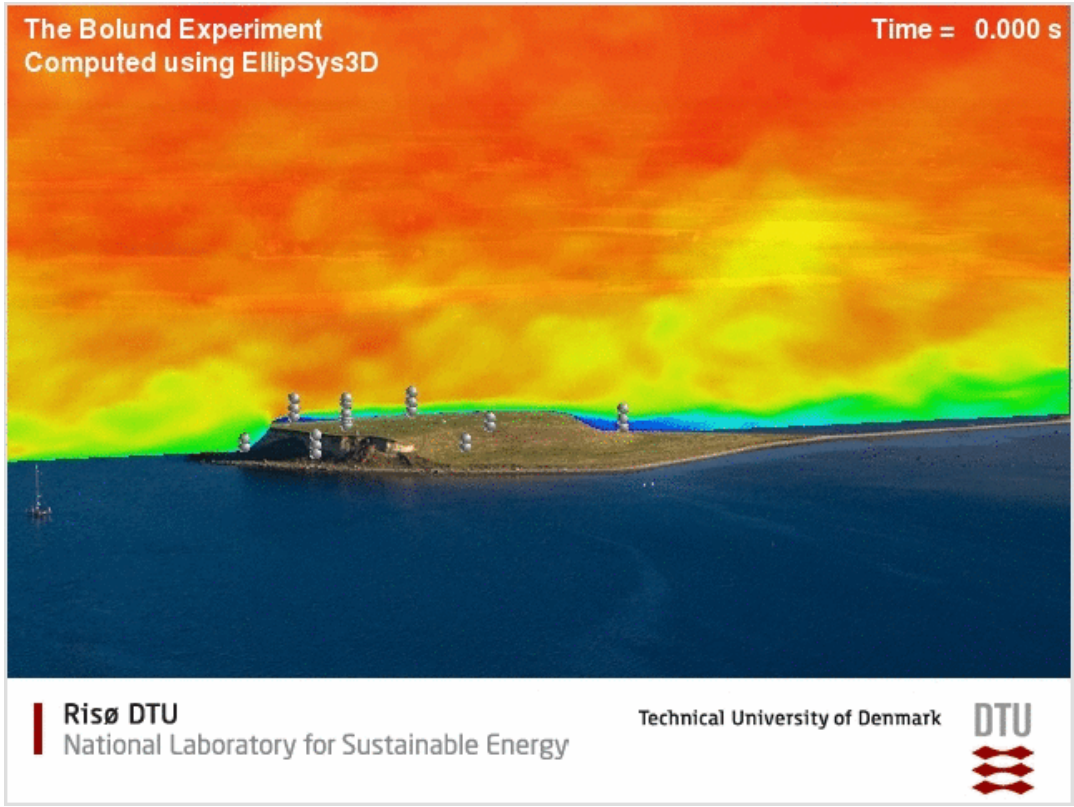
Conclusions

The Blind Comparison

1. Recommendation: RANS k-ε is today's main workhorse, LES has not matured yet.

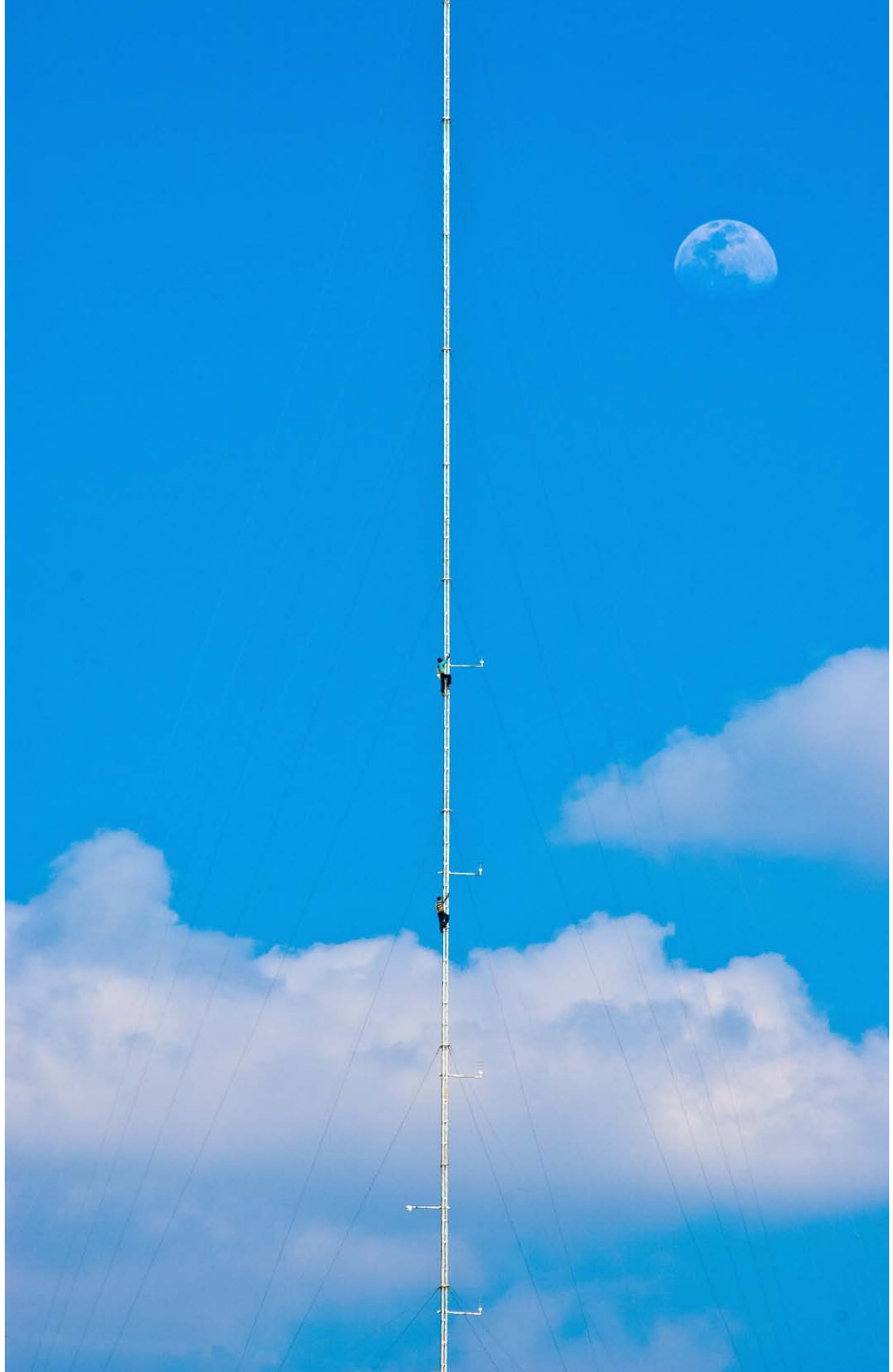
2. 10% error on speed-up and 20% on TKE is what to expect in complex terrain?

3. 7 diff. CFD solvers in top 10: The user is more important than the solver.



Content

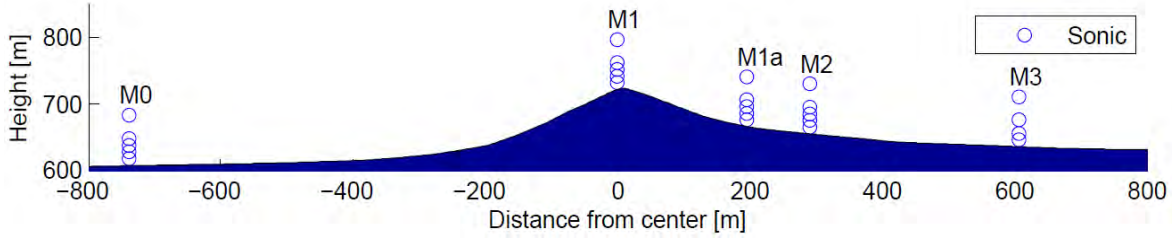
1. The Experiment
2. The Blind Comparison
3. Conclusions
4. Bigger than Bolund?



Benakanahalli

Benakanahalli

Results coming up!



Thank You!

Risø DTU
National Laboratory for Sustainable Energy

Vestas